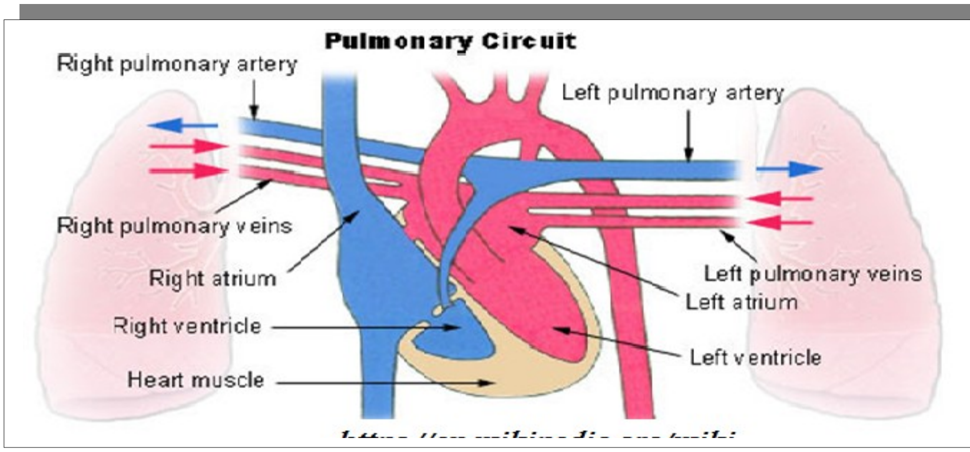
Ventilation Perfusion Ratio (V/Q)

ILOs: By the end of this lecture the student will be able to:

1. List 3 differences between pulmonary & systemic circulation.
2. Explain the regional distribution of pulmonary blood flow.
3. Explain regional distribution in ventilation in the upright lung.
4. Define ventilation perfusion (V/Q) ratio &mention its importance.
5. Predict the consequence of high & low V/Q.
6. Explain shunt (physiological & pathological) as an example of V/Q inequality.



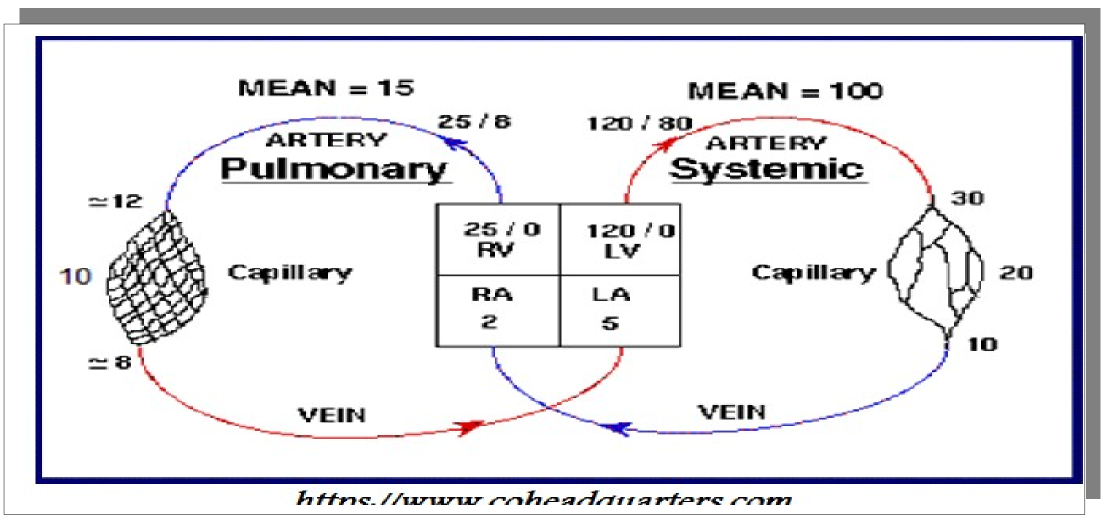
- It is the part of circulation that lies between the right ventricle and left atrium.
- The **pulmonary arteries** are the only arteries that carry *non-oxygenated blood* while the **pulmonary veins** are the only veins that carry *oxygenated blood*.

Characteristics of pulmonary circulation:

- The blood put out by the left ventricle returns to the right atrium and is ejected by the right ventricle, making the

pulmonary vasculature unique in that it accommodates a blood flow that is almost equal to that of all the other organs in the body. Therefore, the pulmonary blood flow = the cardiac output which is about **5 liters**.

- The mean velocity of the blood in the root of the pulmonary artery is the same as that in the aorta (about **40 cm/s**). It falls off rapidly, then rises slightly again in the larger pulmonary veins. It takes a red cell about 0.75 s to traverse the pulmonary capillaries at rest and 0.3 seconds or less during exercise
- Unlike the systemic arterioles, pulmonary arterioles have relatively little smooth muscle fibers in their walls. Pulmonary arterial pressure =**25/10** mmHg with mean pressure = **15** mm Hg.
- The pulmonary capillaries are large, and there are multiple anastomoses, so that each alveolus sits in a capillary basket. Pulmonary capillary pressure is about 7- 10 mm Hg.
- In **<u>pulmonary</u>** circulation, the pulmonary vascular resistance is 1/6 compared to resistance in systemic circulation e.g
- In pulmonary circulation, R= mean pressure/ flow = 15/5= 3 mmHg/L/min while in systemic circulation, R= mean pressure/ flow = 90/5= 18 mmHg/L/min.



Pulmonary and systemic circulations: *Representative areas of blood flow are labeled with corresponding blood pressure (mm Hg).*

<u>Effect of alveolar oxygen on pulmonary blood flow</u>:

- Under most conditions, the pulmonary vessels act as passive, distensible tubes that enlarge with increasing pressure and narrow with decreasing pressure. For adequate aeration of the blood to occur, it is important for the blood to be distributed to those segments of the lungs where the alveoli are best oxygenated. <u>This is achieved by the following mechanism</u>:
- When the concentration of oxygen in the air of the alveoli decreases below normal, the adjacent blood vessels constrict, with increase in the vascular resistance more than fivefold at extremely low oxygen levels. This is *opposite to the effect observed in systemic vessels*, which dilate rather than constrict in response to low oxygen.
- This effect of low oxygen on pulmonary vascular resistance has an important function: to distribute blood flow where it is most effective. That is, if some alveoli are poorly ventilated so that their oxygen concentration becomes low, the local vessels constrict. This causes the blood to flow through other areas of the lungs that are better aerated, thus providing an automatic control system for distributing blood flow to the pulmonary areas in proportion to their alveolar oxygen pressures.

<u>Regional distribution of pulmonary blood flow:</u>

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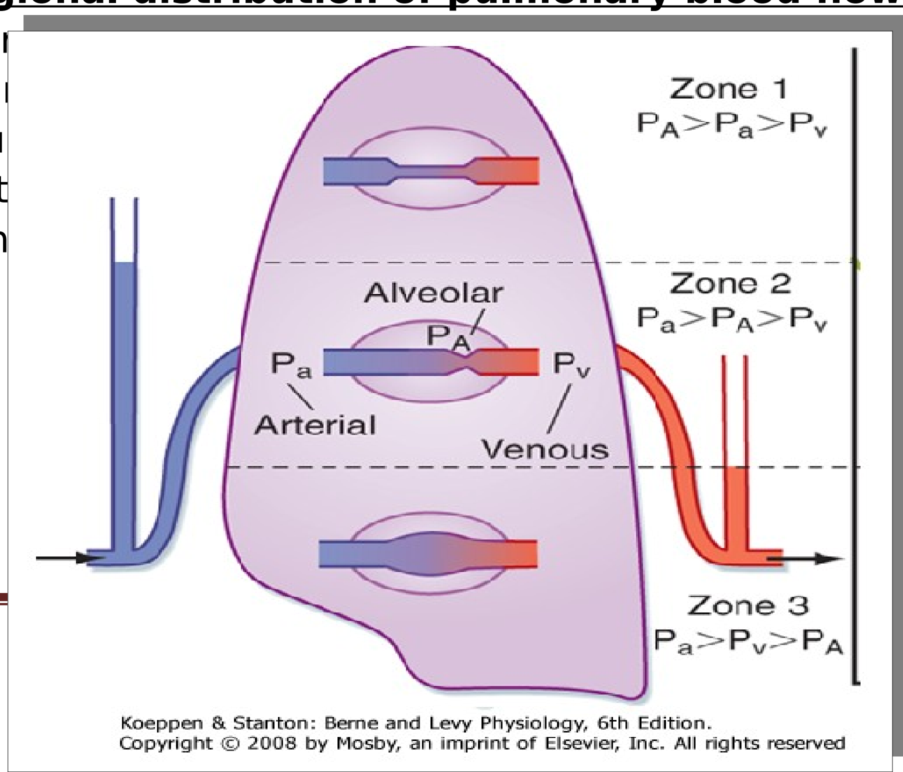


- ***Zone 1:*** very minimal blood flow because the local alveolar capillary pressure in that area of the lung never rises higher than the alveolar air pressure.
- ***Zone 2:*** Intermittent blood flow because the alveolar capillary pressure is greater than the alveolar air pressure
- ***Zone 3:*** Continuous blood flow because the alveolar capillary pressure remains greater than alveolar air pressure during the entire cardiac cycle

Regional distribution of pulmonary ventilation:

- At FRC, the mean value for intrapleural pressure is –5 cm H2O. However, there are regional differences, and the reason for these differences is gravity.

  ** Recall that the pleura is a fluid-filled space.

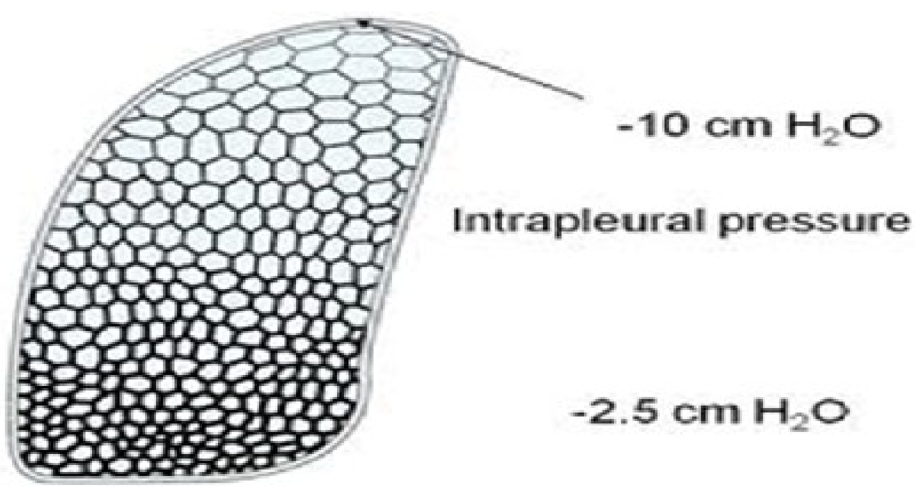


Diagram of normal differences in ventilation and perfusion of the lung in the upright position. Outlined areas are representative of changes in alveolar size (not actual size). Note the gradual change in alveolar size from top (apex) to bottom. Characteristic differences of alveoli at the apex of the lung are

➢ ***Compare:***

At the apex:	At the base:
The IPP is more –ve (-10)	The IPP is less –ve (-2.5)
→ greater TPP gradient	→ less TPP gradient
→ apical alveoli are distended close to their full capacity with stretched, less mobile walls	→ basal alveoli are less distended with smaller volume so can be inflated to a larger size
→ less compliance	→ more compliance
→ Less ventilated	→ better ventilated

Ventilation/Perfusion Ratios:

Def: It is the ratio between the volume of alveolar ventilation (V) and the pulmonary blood flow (Q).

Normal values:

Alveolar ventilation = volume of air that enter in gas exchange per minute = **4.2** liters/min.

Pulmonary blood flow = cardiac output = **5.5** liters/min

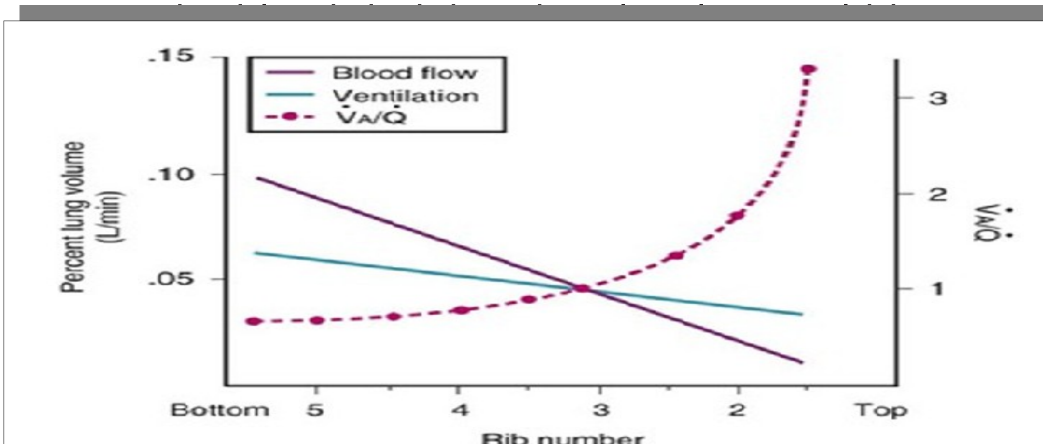
V/Q= Alveolar ventilation / pulmonary blood flow = 4.2 / 5.5 = 0.8

- However, relatively marked differences occur in this ventilation/perfusion ratio in various parts of the normal lung as a result of the effect of gravity, and local changes in the ventilation/perfusion ratio are common in disease.
- Both ventilation & perfusion are not equal throughout the lung so V/Q is **3.3** at the lung apex and **0.6** at the base of the lung.

Importance:

- Adequate gas exchange requires that ventilation & perfusion be matched to each other. So, V/Q ratio is the main determinant of gas exchange across respiratory membrane.
- Therefore, the relative relationship between ventilation and perfusion ultimately determines the alveolar gases. This is **ventilation-perfusion matching**.
- In the normal situation, it would be "ideal" if ventilation and perfusion (blood flow) matched, i.e., the ventilation-perfusion ratio is one. If this were the case, then:
  - PO2 = 100 mm Hg
  - PCO2 = 40 mm Hg

H = 7.40



Pulmonary Physiology, Michael G. Levitzky, 8th edition

Although the above is “ideal,” it is not often encountered.

Toward the **base** of the lung:

• Alveolar ventilation is high relative to the apex (described above).

• Q is high relative to the apex (described above).

• However, relative to one another, Q is higher than alveolar ventilation, thus the ventilation-perfusion relationship is less than 1.0.

• In short, the alveoli are under-ventilated relative to the perfusion. If alveolar ventilation is inadequate, then it follows that PO_2 falls, PCO_2 rises, and blood pH falls (remember that CO_2 generates H^+).

• Thus, the PO_2 at the base is <100 mm Hg and the PCO_2 is >40 mm Hg.

Moving toward the **apex**, the situation reverses:

• Alveolar ventilation is less relative to the base (described above).

• Q is less relative to the base (described above).

• However, relative to one another, Q is less than alveolar ventilation, thus the ventilation-perfusion relationship is greater than 1.0.

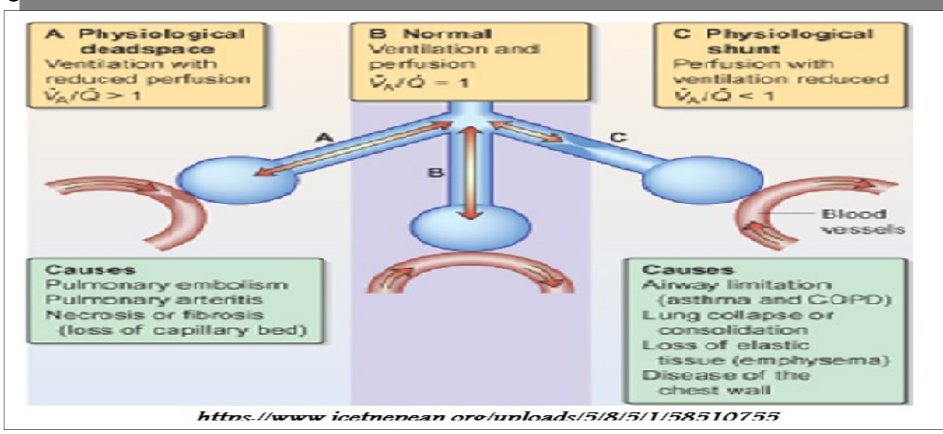
• In short, the alveoli are over-ventilated relative to the perfusion. If alveolar ventilation is excessive, then it follows that PO_2 rises, PCO_2 falls, and blood pH increases (remember that CO_2 generates H^+).

• Thus, the PaO_2 at the apex is >100 mm Hg and $PaCO_2$ is <40 mm Hg.

N.B: There is a ***normal physiologic mismatching*** of ventilation with perfusion from the base to the apex (0.6- 3.3).

Ventilation Perfusion (V/Q)

- If the ventilation to an alveolus is reduced relative to its perfusion, the PO_2 in the alveolus falls because less O_2 is delivered to it and the PCO_2 rises because less CO_2 is expired. Conversely, if perfusion is reduced relative to ventilation, the PCO_2 falls because less CO_2 is delivered and the PO_2 rises because less O_2 enters the blood.



- When a <u>bronchus or a bronchiole is obstructed</u> *(low V/Q i.e ↑blood flow more than air flow) e.g COPD, lung collapse*. Hypoxia develops in the underventilated alveoli beyond the obstruction. The O_2 deficiency apparently acts directly on vascular smooth muscle in the area to produce vasconstriction, shunting blood away from the hypoxic area.

- Conversely, <u>reduction of the blood flow to a portion of the lung</u> *(high V/Q i.e ↑Air flow more than blood flow) e.g pulmonary embolism.* This lowers the alveolar PC_{O2} in that area, and this leads to constriction of the bronchi supplying it, shifting ventilation away from the poorly perfused area.